Letter of Intent

for

LEPTON-PAIR PRODUCTION STUDIES AT THE TEVATRON

C.E. Adolphsen, J.P. Alexander, K.J. Anderson, K.W. Merritt, and J.E. Pilcher

Enrico Fermi Institute, University of Chicago

J.E. Elias

Fermi National Accelerator Laboratory

E.I. Rosenberg

Iowa State University

J.F. Greenhalgh, K.T. McDonald, F.C. Shoemaker, A.J.S. Smith

Princeton University

16225.

Spokesman: K.T. McDonald

LETTER OF INTENT

I. Introduction

As discussed below the apparatus being constructed for E-615, to be used in the P-West high intensity pion beam, has excellent capabilities for extending studies of lepton pair production to Tevatron energies. We will point out some of the significant issues to be studied and, in particular, the advantages of the higher Tevatron beam energies. Also discussed is the expected performance of a modified version of the E-615 detector.

We consider it premature at this time to submit a formal proposal. The experiment could not begin for at least two years and would use an apparatus untried even in its initial application. Experience with the detector and physics developments during this period may indicate emphases and directions which cannot be anticipated now. In view of Laboratory planning for Tevatron hadron beams, this letter is intended to indicate the interesting questions and detector capabilities viewed from our present vantage point.

II. Status of E-615

This experiment, designed to study the production mechanism for μ-pairs at high x_F, will run in the P-West high intensity pion beam. The detector is designed to use instantaneous intensities of ~10^9/sec and to achieve resolutions on the level of a few percent. In particular it is optimized for good acceptance in the helicity angular distribution of the μ-pair. Such acceptance is lost if one requires only relatively symmetric pairs. The experiment was approved in June 1979 and its first beam exposure is expected in December 1981. The delay arises from the existing P-West program and the paucity of HEP hours. It appears likely that data taking will not be complete before Tevatron commissioning begins in early '83. It is perhaps worth mentioning that E-615 is little affected by whether its pion beam is produced by 400 GeV or 1000 GeV protons. The increased yield   from 1000 GeV protons at fixed secondary energies compensates for the reduced repetition rate of the Tevatron.

III. Physics Issues

A. Drell-Yan Normalization

As is widely known, lepton pair production by hadrons is well described
by the mechanism of quark-antiquark annihilation and can be viewed as
the s-channel analog of deep inelastic lepton scattering (see Fig. 1).
One recent development, however, is that the magnitude of the cross
section is claimed to be larger than that expected in the simple quark
model by a factor K = 2.1±0.4. Current analyses assume the difference
to be a constant independent of the kinematic region studied (M^2, s, p_T).
These experiments are limited by statistics and the range of variables
accessible with existing beam energies. One important goal is to
exploit the broadened kinematic range at Tevatron energies in order
to investigate kinematic variations of the K factor.

Present model calculations of this effect suggest that it is only a
weak function of $\tau = M^2/s$.

B. Scale Breaking Effects in the Pion Structure Function

A search for scale breaking effects is straightforward from an experi-
mental point of view. It amounts to measuring the structure function
at fixed values of $\tau = M^2/s$, but over several M^2 ranges. Measurements to
date have been limited to the continuum region between the J/ψ and the T.
At the Tevatron there is the prospect of a structure function measurement
from the region above the T.

It must be admitted that there is no a priori way to separate an M
dependence of the structure function from an M dependence of the K-factor,
although the character of an observed dependence might suggest an inter-
pretation. In any event, experimental information on an M dependence
provides important information to be incorporated in an understanding
of μ-pair production.

C. High x_F Effects in the Pion Structure Function

The E-615 detector has unique capabilities for studying helicity angular
distributions at high x_F where special production mechanisms are believed
to play an important role.[1] The approved E-615 measurements may suggest
significant follow-up studies.

D. High p_T Effects

It has been argued that the large transverse momentum seen in lepton pair production is due to QCD corrections to the simple $q\bar{q}$ annihilation mechanism.[1] Available data are consistent with this interpretation although the tests are not yet very stringent. They are limited to the variation of $\langle p_T \rangle$ and $\langle p_T^2 \rangle$ with s and M^2

Other predictions which have not yet received detailed attention are tests of cross section scaling in the variable $x_T = p_T/p_{T(s)}^{MAX}$ and studies of the helicity angular distributions at high p_T.

The general form of the helicity angular distribution is

$$\frac{dN}{d\Omega^*} \propto 1 + \alpha\cos^2\theta^* + \beta\sin 2\theta^* \cos\theta^* + \gamma\sin^2\theta^* \cos 2\phi^*$$

The QCD corrections mentioned above predict that[2]

$$\alpha = \frac{M^2 - \frac{1}{2} p_T^2}{M^2 + \frac{3}{2} p_T^2} \qquad \text{and} \qquad 1 - \alpha = 4\gamma$$

Thus, for $p_T^2 = M^2$, α is expected to be 0.2 instead of 1.0 as observed at low p_T.

An important measurement is to study the dependence of α on M and p_T.

IV. The Detector

The detector is based on the one constructed for E-615 with changes to accommodate the higher incident energies. A sketch is given in Fig. 2.

The E-615 selection magnet can probably be used without modification although more electrical power would be required. We estimate that with the present power restriction removed, its field integral can be increased by 30% and a detailed TRIM calculation has been performed. This magnet remains useful at the higher Tevatron masses because a strict parallelism requirement is not imposed on the muons (to maximize acceptance) and the geometry is fairly compact. The acceptances given below have been computed using the present geometry of the selection magnet and a 30% increase in p_T-kick.

To maintain good resolution at the higher beam energies it is desirable to increase the strength of the analyzing magnet rather than lengthen the apparatus since the latter is detrimental to the acceptance. Figure 3 shows the acceptance comparison between an analyzing magnet with a 1.3 GeV/c kick using the E-615 distances and a lengthened detector of the same momentum resolution but a 0.83 GeV/c kick. These calculations include a 10 cm x 5 cm dead region where the muon component of the beam enters the detectors downstream of the absorber. Figure 3 shows that at a mass of 15 GeV/c^2 the acceptance is a factor of 3.4 times greater by using the stronger magnet.

Important characteristics of the detector are its acceptance in the x_F, p_T, $\cos\theta*$ variables characterizing the production. Figures 4 and 5 give the x_F and p_T acceptances for masses of 12 and 16 GeV/c^2. The acceptance in $\cos\theta*$ is shown in Fig. 6 for the same masses, with production integrated over appropriate distributions of x_F and p_T. Figure 7 shows the $\cos\theta*$ acceptance as a function of both pair mass and p_T. It is seen that this acceptance is actually slightly flatter at high p_T.

The mass resolution is 1.8% at a mass of 10 GeV/c^2 and an incident pion energy of 500 GeV.

V. Event Rates

Figure 8 shows the expected cross sections at higher beam energies using presently available data and the Drell-Yan formula. The expected pion flux is given in Fig. 9 for protons of 400, 800, and 1000 GeV. The extrapolation to higher energies is obtained from measurements at 400 GeV and the ratio of fluxes at fixed x, predicted for the beam using the Bourquin-Gaillard production formula.

These cross sections, beam flux and acceptances indicate that for a 1000 hour experiment using a pion energy of 500 GeV and 5×10^{12} protons per one minute accelerator cycle, a sample of about 5800 events would be expected above a mass of 10 GeV/c^2 and 280 events above 15 GeV/c^2. These figures indicate the feasibility of a structure function measurement from this interval. We hasten to add that the 5×10^{12} protons/10 sec spill is chosen on the basis of proton availability rather than rate limitations in the detector. It corresponds to $\sim 5 \times 10^8$ π^-/sec and the apparatus is designed to handle several times this intensity.

For studies of high p_T effects the event yield at lower masses is more relevant. For example, in the mass interval between 4 and 5 GeV/c^2 one expects over 100K detected events in the same experiment. Applying x_T scaling·to the CERN NA-3 data[3] one would expect from this mass interval ~800 events with p_T > 4.5 GeV/c. This is an excellent sample for studying the helicity angular distribution at high p_T.

As discussed above it is interesting to determine whether α changes from 1.0 to low p_T to 0.2 at p_T ~4.5 GeV/c as predicted by the QCD model. The statistics are adequate to determine the variation of α with M and p_T.

VI. Conclusions

The increased range of M and p_T accessible at the Tevatron will offer more stringent tests of our current understanding of lepton pair production. To fully realize the advantage of the increased cross sections, however, it would be very desirable to maintain the number of integrated protons per experiment comparable to experiments at present energies.

REFERENCES

1. See, for example, the review of Berger, SLAC-PUB-2314 (1979).

2. J.C. Collins, Phys. Rev. Letters 42, 291 (1979); and C.S. Lam and Wu-Ki Tung, Phys. Rev. D21, 2712 (1980).

3. J. Badier et al., submission to International Conference on High Energy Physics, Madison, 1980, CERN/EP 80-150.

Figure Captions

Fig. 1. The mechanism of lepton pair production contrasted with deep
         inelastic lepton scattering.

Fig. 2. Detector layout for Tevatron running.

Fig. 3. Acceptance versus pair mass for a p_T kick of 1.3 GeV/c in the
         analyzing magnet (labelled higher field) and a lengthened
         apparatus giving the same resolution with an analyzing magnet
         of 0.83 GeV/c kick. For this calculation x_F, p_T, $\cos\theta^*$ of
         the pair are generated according to existing data.

Fig. 4. Acceptance in x_F for two mass values.

Fig. 5. Acceptance in p_T for two mass values.

Fig. 6. Acceptance in $\cos\theta^*$ for two mass values.

Fig. 7. Acceptance in $\cos\theta^*$ for two mass values and two p_T values.

Fig. 8. Muon pair production by π^- beams of 200, 400, and 600 GeV.
         The 200 GeV curve is based on existing data.

Fig. 9. Expected π^- flux in the P-West beam for incident proton
         energies of 400, 800, and 1000 GeV. The 400 GeV curve
         is from direct measurements.
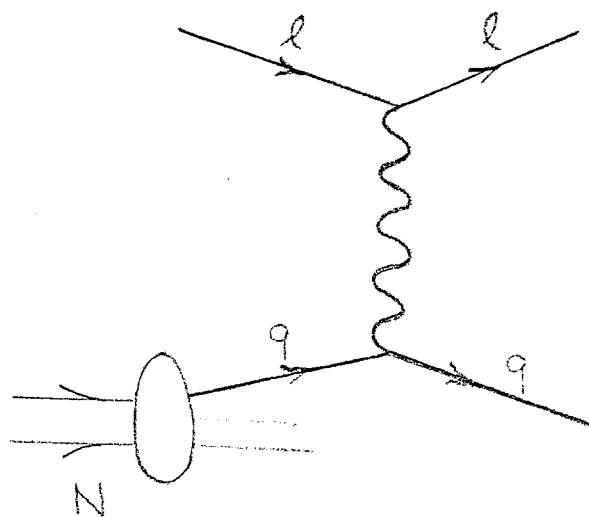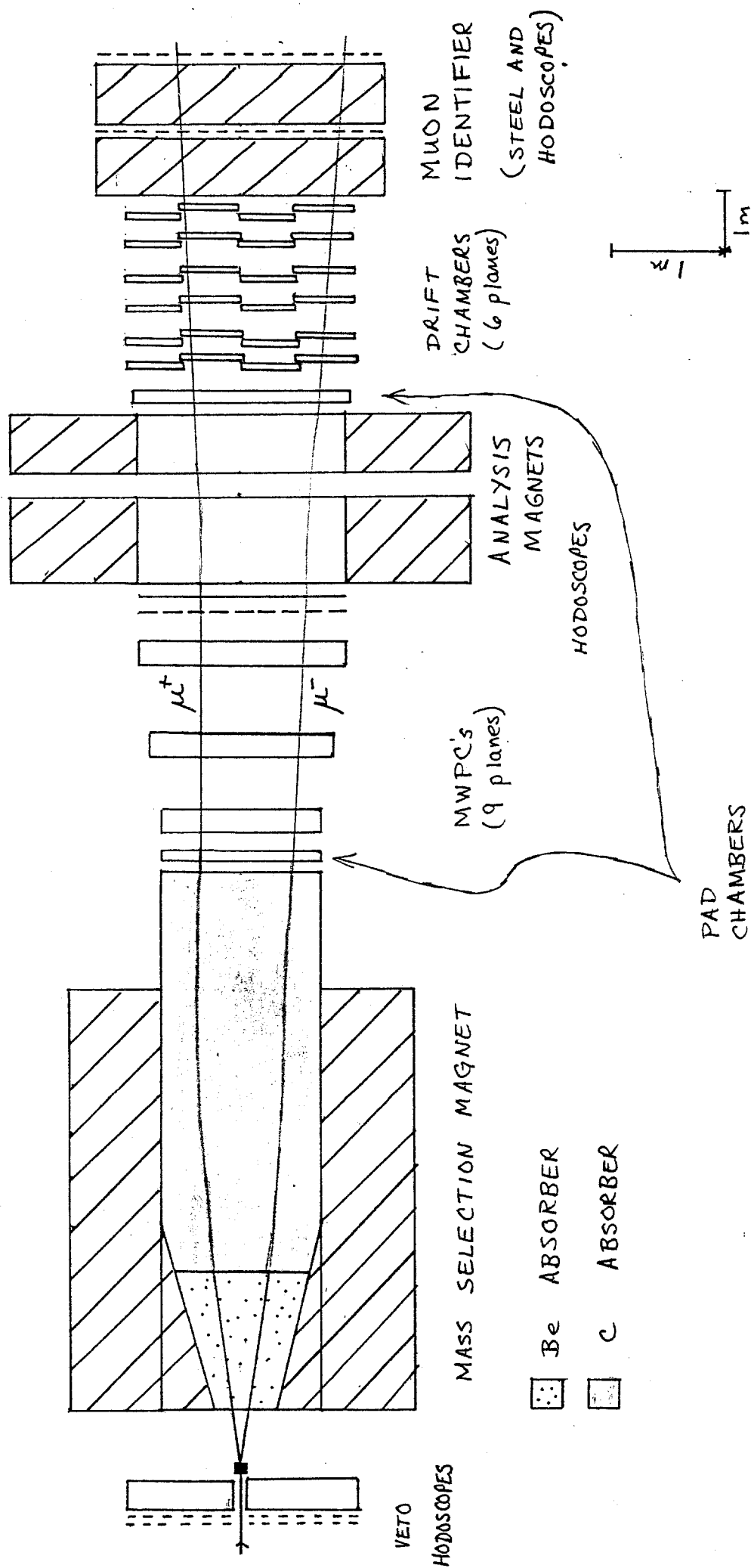
Deep Inelastic
Lepton Scattering
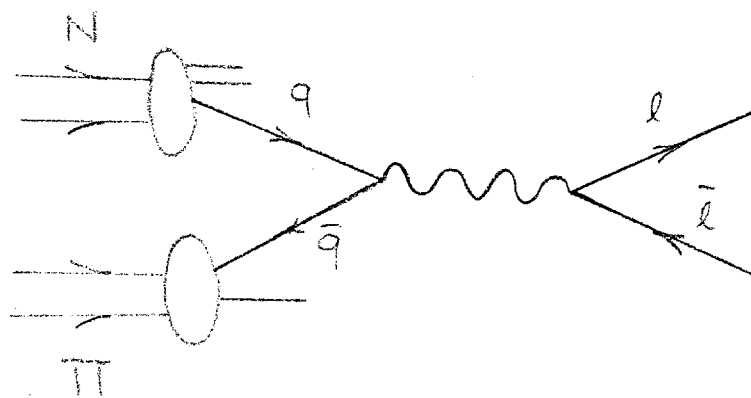
Lepton Pair
Production

Figure 1

Figure 2

PROPOSED E615 CONFIGURATION FOR 600 GeV π's INCIDENT

MASS ACCEPTANCE OF MODIFIED
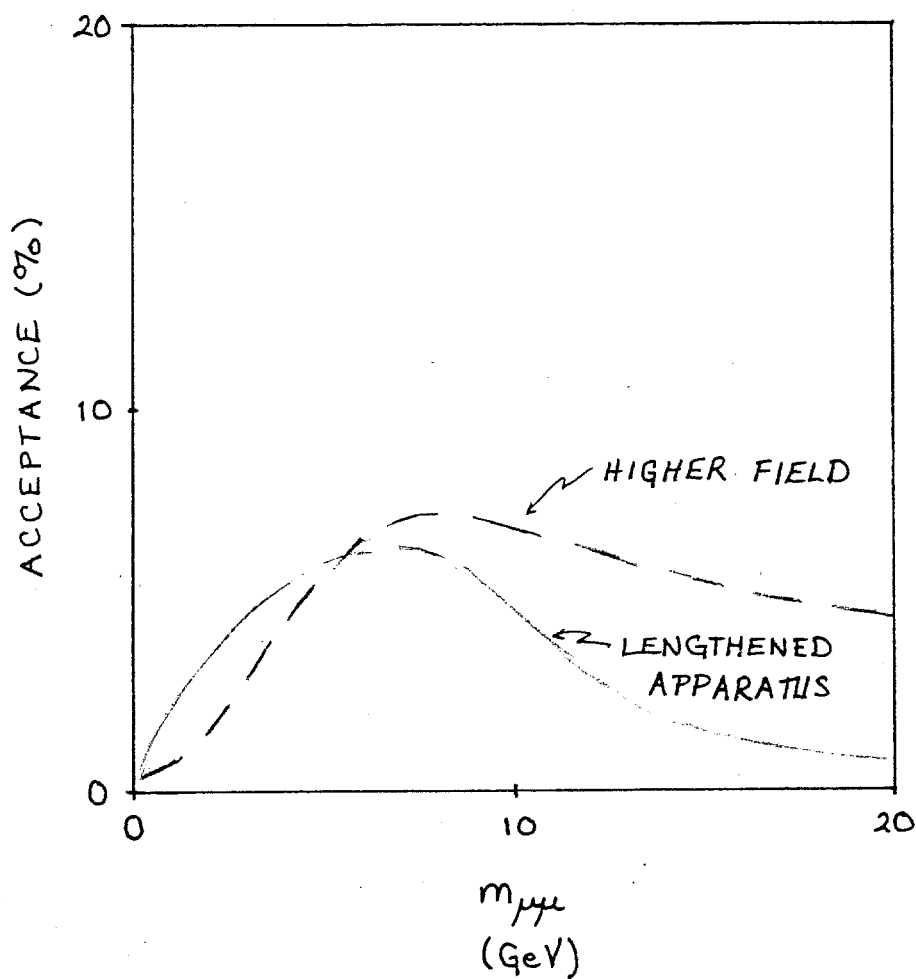
E615 APPARATUS USING INCIDENT

600 GeV π BEAM

Figure 3

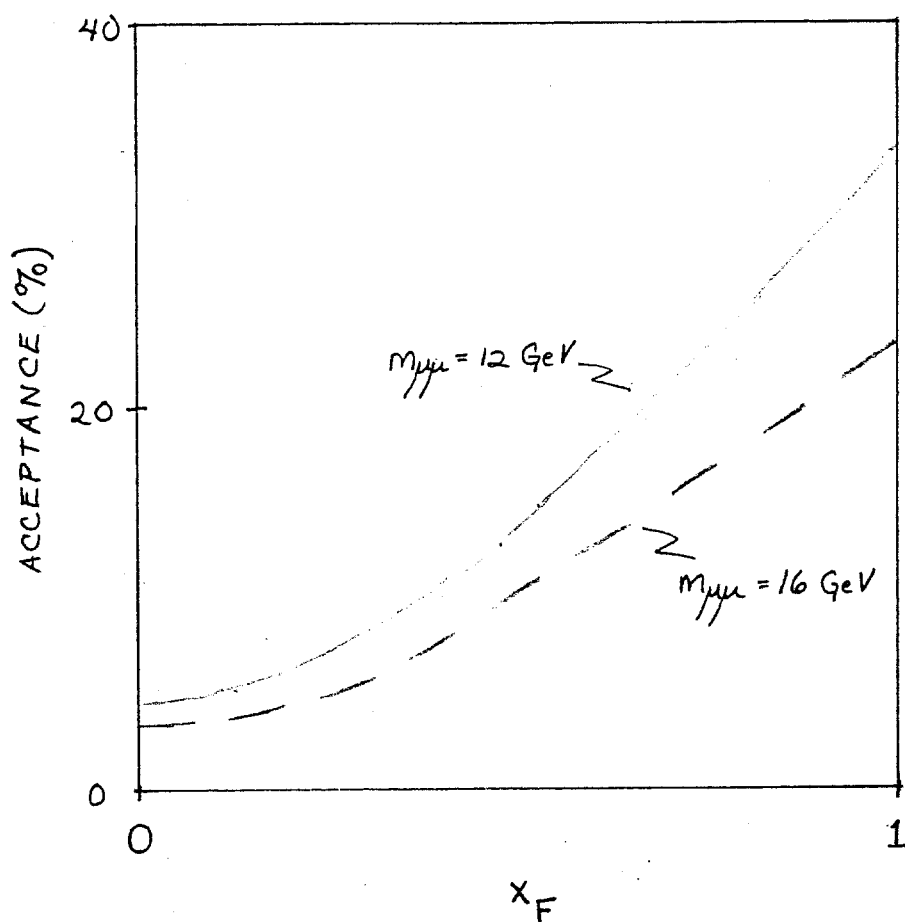TRIGGER ACCEPTANCE OF E615 APPARATUS
VS. X_F

$(E_\pi = 600 \text{ GeV}; \text{ HIGH FIELD})$

Figure 4

TRIGGER ACCEPTANCE OF E615 APPARATUS
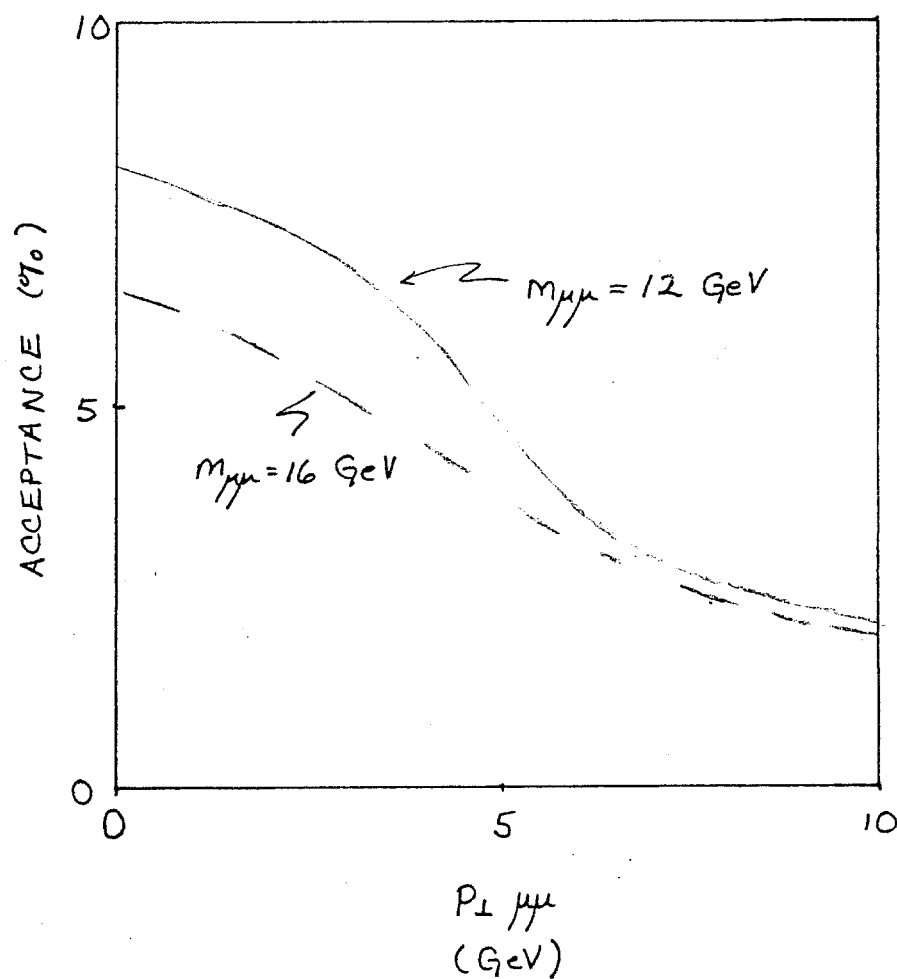
vs. $P_\perp \mu\mu$

$(E_\pi = 600 \text{ GeV}, \text{ HIGH FIELD})$

Figure 5

TRIGGER ACCEPTANCE OF E615 APPARATUS
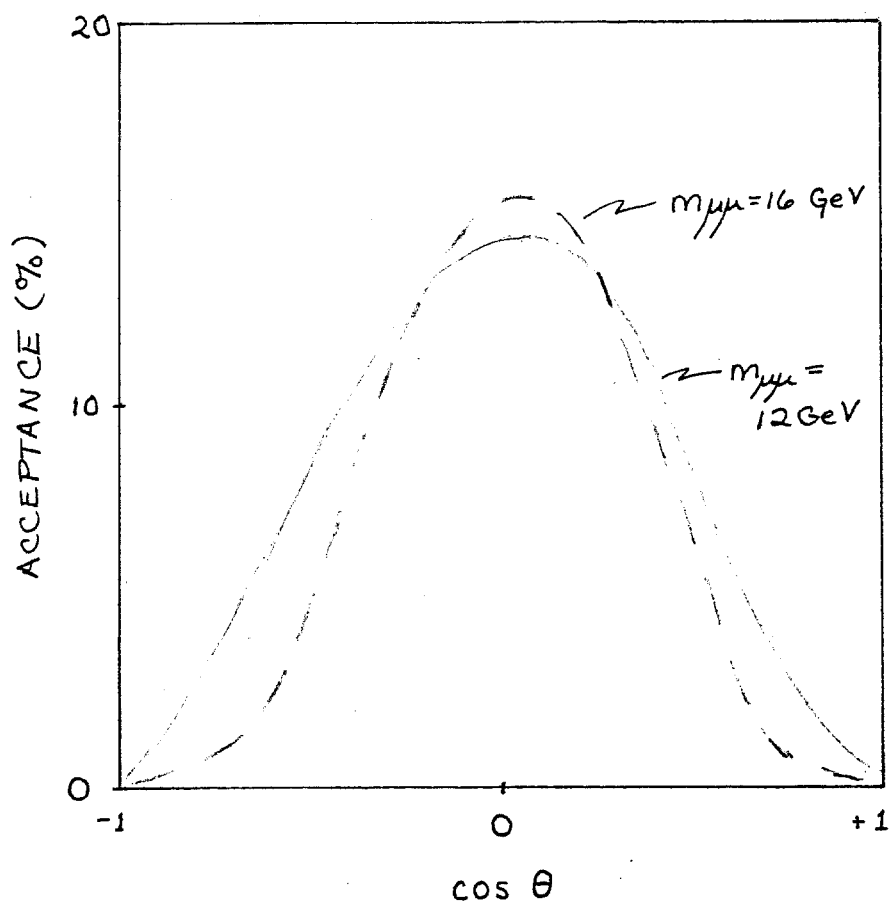VS. COS θ

($E_\pi = 600$ GeV; HIGH FIELD)

Figure 6

ACCEPTANCE VS. COS θ AS A
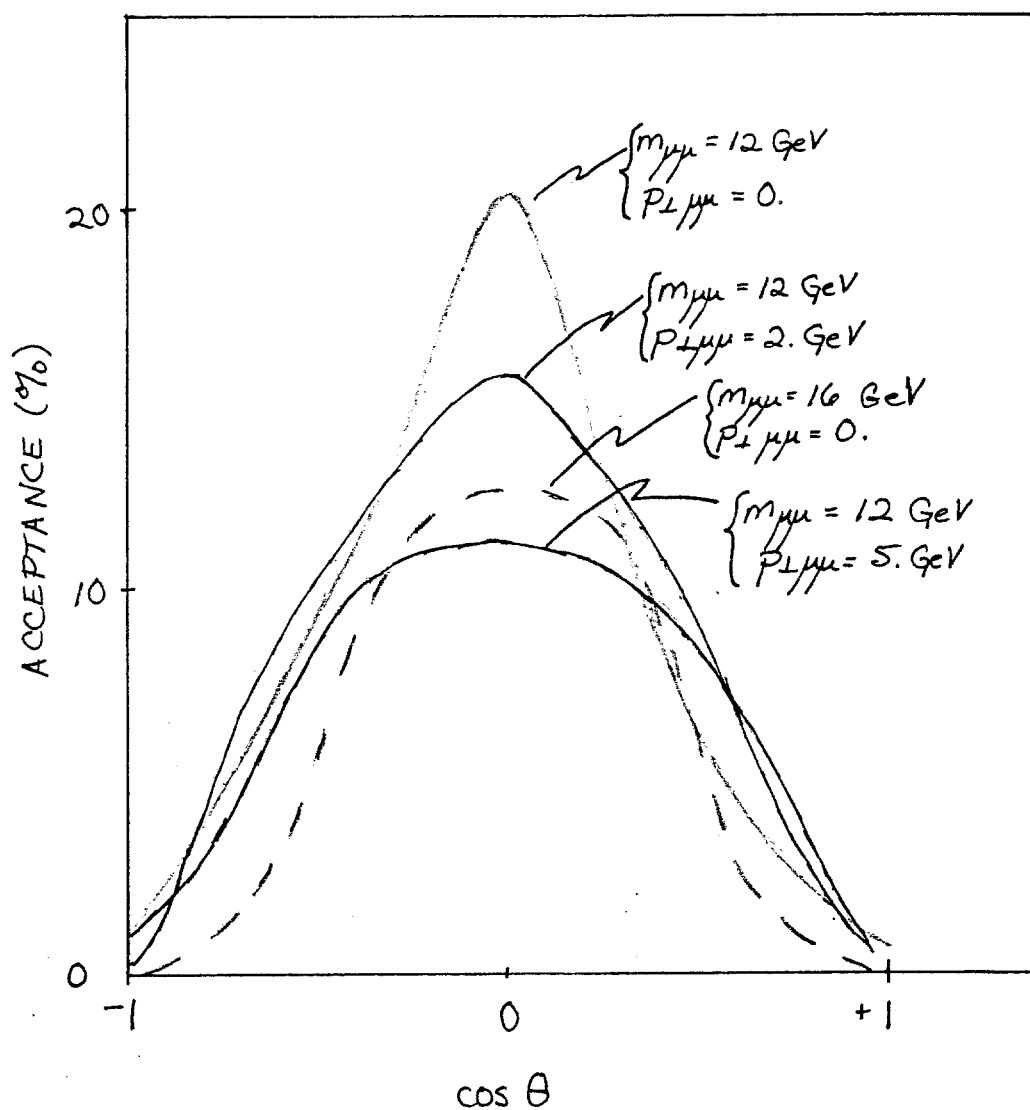FUNCTION OF $m_{\mu\mu}$ AND $P_{\perp\mu\mu}$

Figure 1

Figure 8
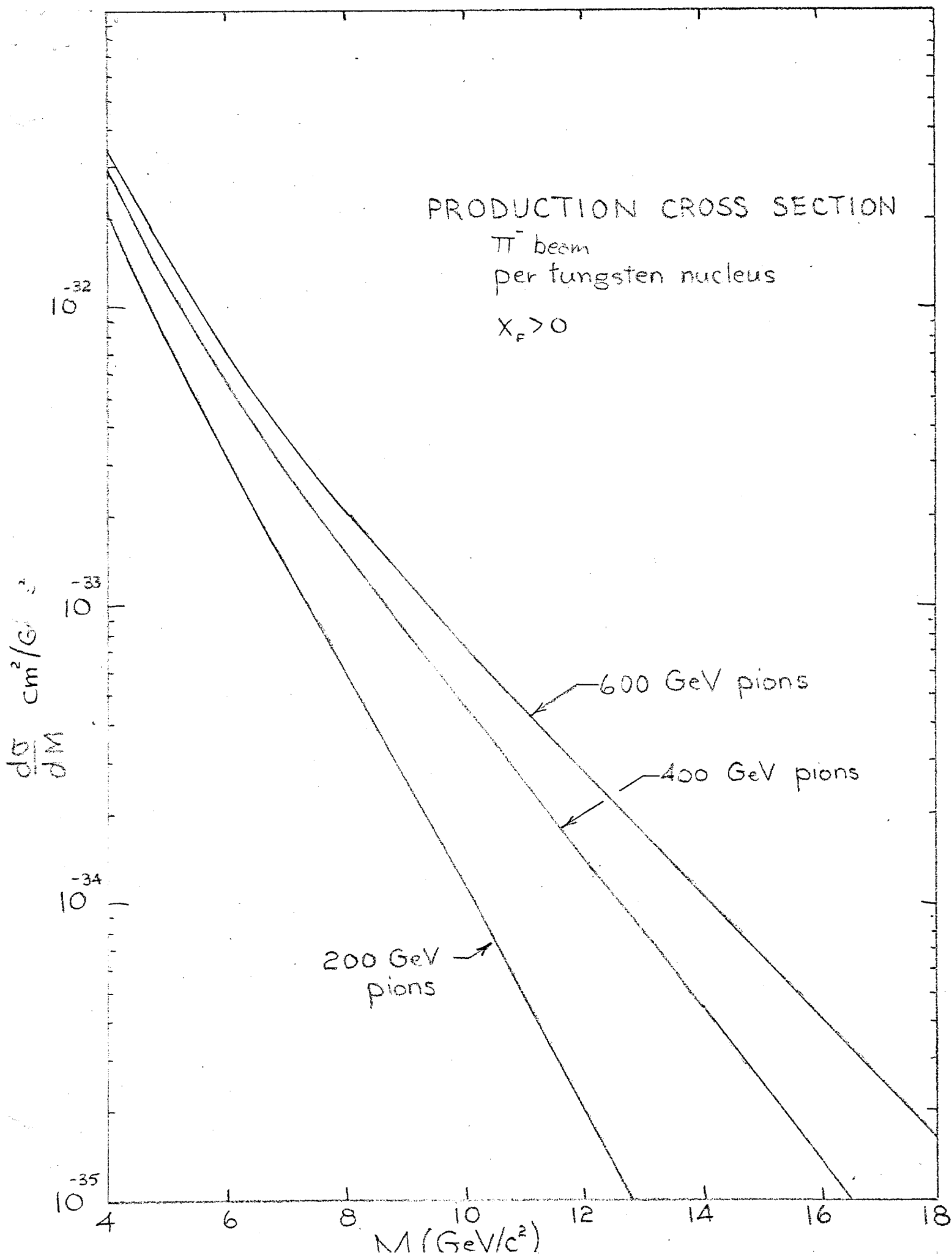
PRODUCTION CROSS SECTION
π^- beam
per tungsten nucleus

$X_F > 0$

600 GeV pions

400 GeV pions

200 GeV pions

$\frac{d\sigma}{dM}$ cm²/GeV²

M (GeV/c²)

Figure 9